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AN EFFECT OF WEAR BEHAVIOUR ON B_4C PARTICLES REINFORCED WITH Al-Si ALLOY PREPARED THROUGH POWDER METALLURGY METHOD USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

This present study is to develop the statistical model that might be used to forecast the wear of Al–12Si-x B_4C (x = 0, 4, and 8 wt. % of B_4C) composites have faith in densification of the powder throughout compaction and sintering. The L17 orthogonal array was selected for investigating the response surface methodology (RSM) design using three factors with one replicate. Analysis of Variance (ANOVA) was utilized to explore the influencing input factors on Wear Loss (WL). The hardness of the composites will rise because of the increased wt. % of B_4C. The Pin-on-disc and Scanning Electron Microscope (SEM) were used to examine the wear and friction, and characterization of Al–12Si-x B_4C composites respectively. The mathematical model was applied by design expert software so as to precise the influence degrees of the most wear variables like reinforcement, sliding distance and load on WL. The results specify that the load and sliding distance is that the dominant factor affecting WL mainly.

***KEYWORDS:** Al-Si- B_4c Composites, SEM, ANOVA, RSM &Wear Loss*

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Original Article

INTRODUCTION

Aluminium alloy reinforced with boron carbide is deliberate to be a possible substitute material with conservative monolithic aluminium alloys in numerous applications due to its enhanced specific strength and improved stiffness, less density, little thermal expansion coefficient and outstanding resistance to wear. Aluminium-based composites are broadly utilized in several industries that are not inadequate to aerospace, automotive, defence, naval, electronic packaging, thermal and sports [1]. Several techniques have been used for manufacture aluminium-based composites, for example, liquid metal in filtration, squeeze casting, diffusion bonding, electro deposition, powder metallurgy and stir casting process. Whereas utilizing a Powder Metallurgy (P/M) method for production of aluminium- based composites, improved mechanical properties can be achievedmeanwhilestrengthening materials are evenly disseminatedabove the matrix material [6]. Subsequently, in

this methodlittle temperature is utilized for production when related to melting route, thus it evades chemical reaction among the matrix and strengthening material [7]. An additional advantage of the P / M method is in its facility to fabricate near net shape component parts for the required size at little cost and offer respectable dimensional tolerance for the difficult geometries. Aneconomical way of solving these problems was the use of strengthening fineparticles such as B_4C, TiC, TiB_2, ZrC, SiO_2, Al_2O_3, SiC particles and whiskers or other fine particles or composites as alloyingfine particles. The inclusion of these ceramics and alloying fine particles makes it potential toenhance the specific elastic modulus of aluminium-based composites,enrich its thermal properties etc. [2]. By thesestrengthening B_4C, the composites have reduced densities and also improved wear resistance. In recent times, there has been a development of interest in composites comprising low density and reinforcements at low cost. The Al hybrid MMCs on the addition of graphite (Gr) particles as the secondary fortification shows better wear performance. Thefortification silicon carbide (SiC) was various from 0to 12 wt.% and Gr particlewere retained at 4wt% in all the combinations. The trials wereperformed by a 4 - factor, 5-level centralcomposite rotatable design which diminishes the number of trials. The factors taken are sliding velocity (SV), Sliding Distance (SD), Load (L) and wt% of SiC and Gr particles with 5 levels. Response Surface Methodology (RSM)was utilized to increase the numerical model to forecastthe wear rate and optimize the output variables fora least wear rate. It is initiated that enhance in SiC and Gr volume has improved the wear resistancewhich produced in little wear rate when evaluated with unreinforced Al alloy. Response surface methodology as per Box–Beheken method was utilized to design the experiments, replica and investigate the tribological performance of Al-Si-10Mg, Al-Si-10Mg/10SiC and Al-Si-10Mg/20SiC composites. A best wear provision wasacquired when the process parameters, such as, the SV, L and wt.%SiC_p, were at 4 m/s, 10 N and 20 %. Both GA-RSM approaches were lucratively utilized to forecast the smallest wear rate circumstance of AlSi10Mg/10SiC_p composites with an exactness of 94%. The input parameters were optimized and modelled utilizing RSM for the wear behaviour of Al 2219-SiC_p composite. The input factors, for example, wt. % of reinforcement, sintering temperature, L and SV were measured. The outcome revealsexcellent prediction exactness of about 85% on average of all wears characteristics. Consequently, this paper explores an effort made to scrutinize the interdependence of reinforcement, SD and load as input variables and mathematical replica to predict where loss of Al-12Si-xB_4Ccomposites utilizing a Box-Behnken Design (BBD), analysis of variance, the normal probability and wear loss plots.

EXPERIMENTAL PROCEDURE

The electrolytic Aluminium and Silicon were obtained and the immaculateness of 99% and a molecule measure lesser than 20 and 40 μm from M/S. MEPCO metal powder company, Thirumagalam, Tamilnadu, India. Boron carbide powder with immaculateness of 99.9% and a molecule measure lesser than 44 μm utilized as an auxiliary strengthening material was obtained from Sigma Aldrich, Germany. Nano sized B_4C particles were blended by processing B_4C micron powders with the measure of 44 μm in a ball mill utilizing a solidified tungsten carbide vial and balls with 10 *mm* in diameter. The ball to powder proportion and rotational speed were 20:1 and 300 *rpm*, correspondingly. Toluene was utilized as a processing medium and the granulating zone involved 80% of the chamber volume. The minimum size of the elements was ≤100 *nm*, subsequently 60 *h* grinding. A SEM pictures of a specimen by examining the surface with an absorbed beam of electrons. The electrons intermingle with molecules in the specimen, generating different signals that comprise evidence approximately the specimen surface topography and combinations. VEGA3, TESCAN (Czech Republic) was used to obtain the SEM images of the specimen. The samples were first subjected to gold ion sputtering. Ion sputtering is employed to increase the conductivity of the specimen surface. The SEM microstructures of the composites

are shown in the following figures. Figure 1 (a) demonstrates the SEM microstructure of Al elements. It can be observed that aluminium has spherical structure. Figure 1 (b) demonstrates the SEM image of Si element and it is observed to have flattened and large flake like elements. Figure1 (c) demonstrates that the B_4C particles with rhombohedral shape. Rule of mixtures was utilized to evaluate the varying weight fractions of Al-12Si-xB_4C (x = 0, 4 & 8 wt.%). Mechanical Alloying (MA) was conceded out for varying combinations utilizing a ball mill with a tungsten carbide container and balls of 10 mm diameter belowarg on environment. The ball to powder weight ratio was 20:1 and was utilized to alloying the varying composites for each 1 *h*. To elude the rust and contamination of the MA processes, the process control agent was utilized in argon environment. From the SEMpicture it was identified that the milled B_4C nanoparticle was uniformlydispersed in all the Al-12Si-xB_4C composites. The SEM picture also displays that the piercing crinkled arrangement of Al was fragmented, and for the reason that the milled B_4C particles were simplyconnected with the Al-12Si alloy. To rise the power of the lenient Al material irrespective of varying wt.%, milled B_4C particles were strengthenedinto the matrix. It was evidently confirmed in the SEM pictures exposed in Figure 2(a–c). It was perceived that all the elements were disseminated consistently through the compositions. This was owing to the stable state mingling of powders by utilizing ball mill. The alloyed powder is compacted in a compression testing machine to achieve 30*mm* height and 10 *mm* diameter with applied pressure of 800 *MPa.* The compressed specimen's are sintered using argon gas purging heating furnace for 120 *min* at 550°*C* and furnace cooled to the surrounding temperature. The sintered compressedspecimen was subjected to wear test by pin-on-disk method. The alloyed powder mixtures were characterized using SEM. The SEMpictures of Al-Si,Al-12Si-4 B_4C and Al-12Si-8B_4Celements are shown in Figure 2 (a –c).

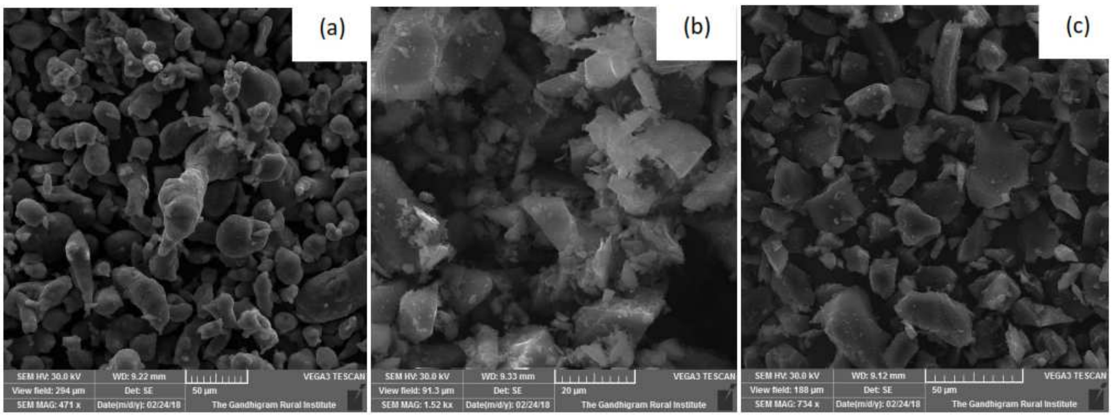


Figure 1: Demonstrates the SEM Pictures of Powders (a) Al, (b) Si, and (c) B_4C

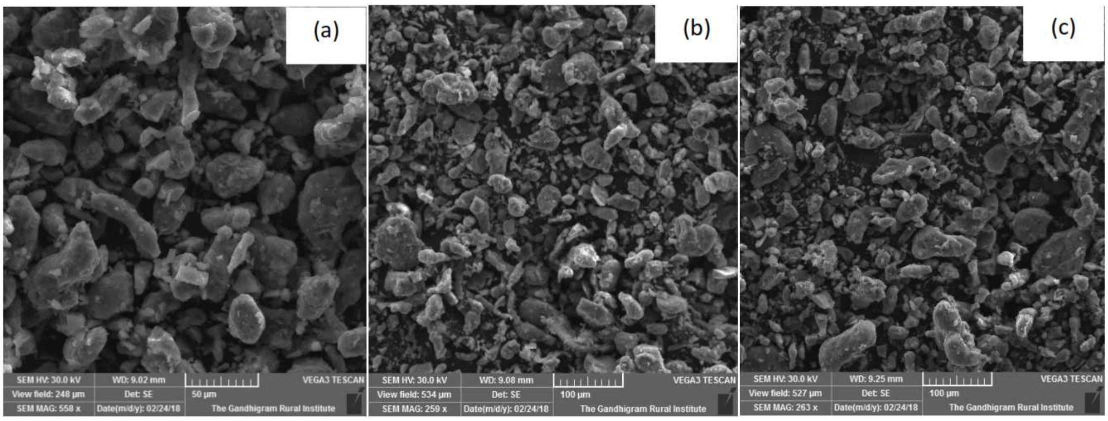


Figure 2: Demonstrates the SEM Pictures of Mixed Powders (a) Al-12Si, (b) Al-12Si-4B_4C, and (c) Al-12Si-8B_4C

WEAR TEST

The wear test specimens 10 mm x 30 mm are obtained from the sintered composites bymachining. The end surface of the specimens is cleaned and polished with 600 grade followed by1000 grade abrasive paper. The wear testwas conducted on pin-on-disc deviceat atmospheric temperature affordingto ASTM G99-05 standard. Throughout the wear assessment, the load on the pin was applied normal to the sliding direction of a revolving EN 31 steel plate of *HRC* 64 and surface roughness0.0001 microns were used to conduct the test. A computer aided data acquisition records the weightloss in grams was recorded.

PERSUADE OF B_4C CONTENT ON DENSITY

Approximation of the Experimental Density (ED) for the sintered Al-12Si-xB_4C composites utilizing the Archimedes rule was exposed in Table 1. In Table 1 it is exposed that the ED of the sintered Al-12Si-xB_4C composites was diminished owing to the bunch of B_4Celements and openings remaining in the green specimen throughout compression. The Theoretical Densities (TD) of the composite powder blends were estimated utilizing the rule of mixtures, eliminating the sponginess. However, the ED was deliberate utilizing the Archimedes rule for as interred specimen. The difference among the TD and ED displays the % of sponginesss existing in the specimens. Consequently, the density was varying between TD and ED values. The ED of Al-12 Si-xB_4C composites were improved. A weight balance with aprecision of 0.001 mg was utilized to evaluate the specimens. The TD was calibrated for the Al-12Si-xB_4C composites for different composites utilizing the rule of mixtures [12]. The relative density after sintering was nearby 92% and it exposes that the sponginess of the composites has diminished by up to 8%. The wear resistance of the combinations was diminished by retaining the porosity level.

Table 1: Density of the Composites

Composites	ED	TD
Al-12Si	2.4426±21	2.6556
Al-12Si-4B_4C	2.4283±18	2.6484
Al-12Si-8B_4C	2.4272±13	2.6412

RESPONSE SURFACE METHODOLOGY

Response surface methodology is a set of numerical and geometric methods that are helpful for budding, progressing, and best route. This processmay be utilized by several investigators for forecasting the wt.% of composites, sliding distance, load, and so forth. It is frequentlyuseful in conditions where the response of significance is affected by more than a few parameters and the goal is to optimize this response. The Design Expert software V11 was utilized to extend the trial design for RSM. A quadratic model of second-order form was planned to signify the connection among WL. The routine of the replicable subject to a huge number of parameters that could beperform and relate in a difficult way. In the current work, the wt.% of B_4C, SD and L are measured as self-sufficientparameters and the response variable is the WL. In RSM, the computable form of the connection among the preferred output and the self-determining input parameters could be characterized as exposed in the subsequent equation.

$$y = f(A, B, C)$$

where, y is the preferred output and fis the output function. The BBD is a first-order design improved by extra

points to permit evaluation of the modification factors of a second order model. The factorial segment of the BBD is the RSM plan with all arrangement of the factors at two levels (low -1 and high +1). The testing factors at three levels with their choice are offered in Table 2 and Table 3 exposes the trial runs with the input factors and outresponse.

Table 2: Experimental Factors and Number of Levels used in Design – Expert 9.0.5

Testing Parameter	Symbol	Level 1 (-1)	Level 2 (0)	Level 3 (1)
Reinforcement (A)	Wt.% of B_4C	4	6	8
Sliding distance (B)	m	800	1200	1600
Load (C)	N	16	24	32

Table 3: Shows the Experimental Run and Input Factors with its Response

Std Run	Run	Input Factors			Response
		wt.% of B_4C	SD	Load	Wear Loss
13	1	0	0	0	0.186756
8	2	1	0	1	0.211799
16	3	0	0	0	0.186756
9	4	0	-1	-1	0.106018
6	5	1	0	-1	0.139119
12	6	0	1	1	0.302333
17	7	0	0	0	0.186756
2	8	1	-1	0	0.132325
1	9	-1	-1	0	0.146600
10	10	0	1	-1	0.178698
11	11	0	-1	1	0.180357
4	12	1	1	0	0.218119
3	13	-1	1	0	0.258725
15	14	0	0	0	0.186756
7	15	-1	0	1	0.246022
14	16	0	0	0	0.186756
5	17	-1	0	-1	0.137310

RESULTS AND DISCUSSION

Persuade of B_4C ontent on Hardness

The hardness of any material directly influences the wearresistance properties. In the present study trial experiments were first conducted to check the influence of reinforcementson microhardness. Vickers microhardness tests were carriedout at 150 gram load with dwell of 30 seconds. The results ofVickers microhardness are shown in Table 4, which revealed that the presence of B_4Cparticles significantly improveshardness in comparison to Al. Further, the influence of varying weight percentages of reinforcements is shown in Table 4, which show that hardnessincreases linearly with increase in B_4Cweight percentage. It was found that at higher reinforcement levels, the variation inmicrohardness occurred which may be due to theagglomeration of reinforcements in matrix phase. This aggregation of particles causes differential hardenedphases and hence causes higher variations. It can be clearly seen that the highest microhardness of 71±14 after sintered and 76±20 VHNafter wear test is shownby the nanocomposite containing 8B_4C reinforcement. In comparison to the base alloy, the reinforced composite containing 8B_4Cshows 19.71 and 18.42%higher microhardness. Further, to study the effect ofmicrohardness on tribological properties, dry sliding wear tests were performed and results are reported in the nextsection.

Table 4: Shows the Vickers Hardness of the Composites

Compositions	Hardness After (VHN)	
	Sintered	Wear Test
Al-12Si	57±0.24	62±0.17
Al-12Si-4B_4C	64±0.18	70±0.21
Al-12Si-8B_4C	71±0.14	76±0.20

PERSUADE OF B_4C CONTENT ON ENERGY DISPERSIVE X-RAY SPECTROSCOPY

Energy-dispersive spectroscopy is a scientific method utilized for the elemental analysis of powder samples Al, Si, B_4C, Al-12Si, Al-12Si-4B_4C, and Al-12Si-8B_4C composites respectively. It relies upon the investigation of a correspondence specific source of X-ray excitation. Its portrayal abilities were expected in extensive portion to the vital rule that every component has a sole atomic assemblypermitting a sole arrangement of crests on its X-Ray range. To fortify the radiation of particular X-ray as of a composite, a high-energy ray of exciting elements, for example, electrons or protons or a beam of X-rays was centered on the sample being examined. Figure 3 (a-f) demonstrates the EDS arrangement of the distinctive composites subsequent to sintering. In this current investigation, EDS arrangement was utilized to affirm the elements existing in the Al-12Si-xB_4C composites.

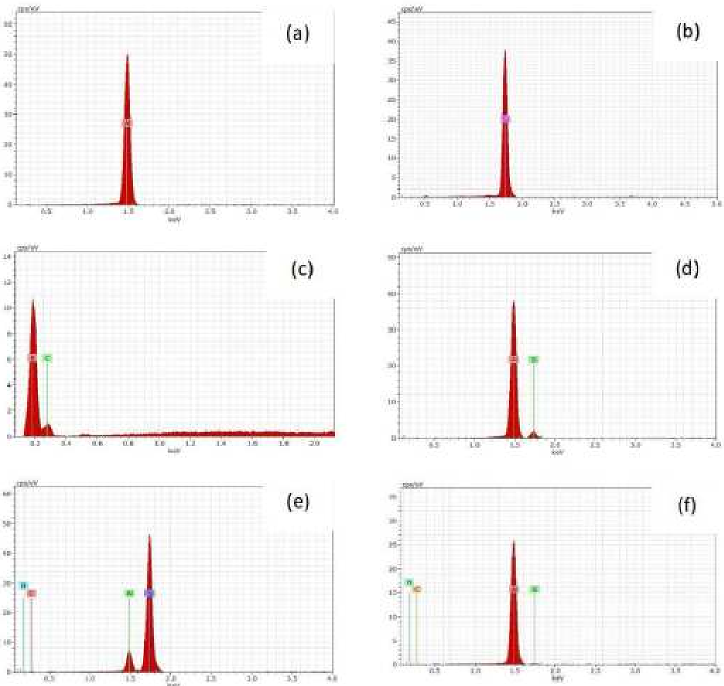


Figure3:(a-f) Shows the EDS Graphs of the Received and Mixed Powders (a) Al, (b) Si, (c) B_4C, (d) Al-12Si, (e) Al-12Si-4B_4C, (f) Al-12Si-8B_4C

ANALYSIS OF VARIANCE FOR WEAR LOSS

With the end goal to research the fundamentally influencing parameters the quality, ANOVA of data was executed for evaluating the impact of wt.% of B_4C, SD and load on the aggregate fluctuation of the outcomes. Furthermore, the Fisher's F-test can likewise be utilized to decide the parameters which significantly affect the response parameters when F is huge. The outcomes of ANOVA for WL of Al-12Si-xB_4C composites appear in Table 5. From the ANOVA table it is afresh explored that significancelevel of $\alpha=0.05$, i.e. for the confidencelevelof 95%. It has been

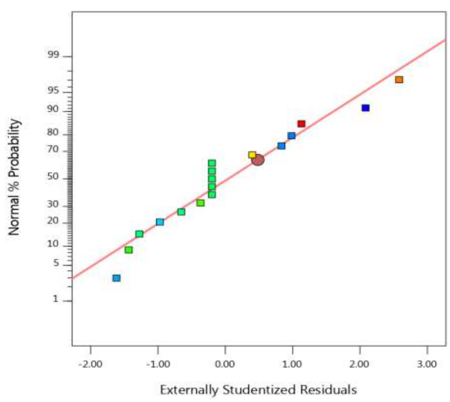
adequately that P< 0.05 is implied that the conduct of the elements statisticallysignificant or more 0.05 irrelevant to the model. Particularly the load has a more prominent impact when contrasted with the rest of the elements. Thus in this investigation, it is discovered that SD, and fortification elements hasless influence compared to that of load on the WL separately.

Table 5: ANOVA for Wear Loss

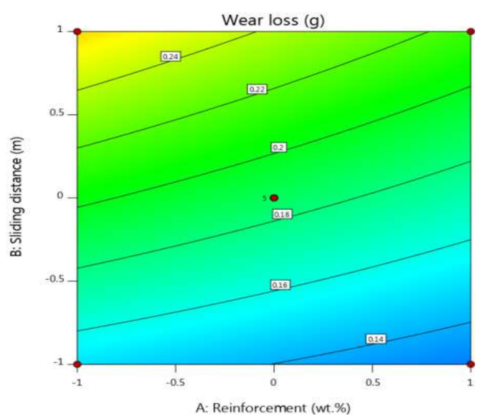
Source	Sum of Squares	df	Mean Square	F-value	p-value	Remarks
Model	0.0455	9	0.0051	248.32	< 0.0001	significant
A-Reinforcement	0.0021	1	0.0021	104.47	< 0.0001	significant
B-Sliding distance	0.0193	1	0.0193	946.92	< 0.0001	significant
C-Load	0.0223	1	0.0223	1096.6	< 0.0001	significant
AB	0.0002	1	0.0002	8.52	0.0224	significant
AC	0.0009	1	0.0009	45.56	0.0003	significant
BC	0.0006	1	0.0006	29.86	0.0009	significant
A^2	$1.32E^{-08}$	1	$1.32E^{-08}$	0.0006	0.9804	insignificant
B^2	0	1	0	0.9392	0.3648	insignificant
C^2	0	1	0	1.82	0.2194	insignificant
Residual	0.0001	7	0	-	-	-
Lack of Fit	0.0001	3	0	-	-	-
Pure Error	0	4	0	-	-	-
Cor Total	0.0456	16	-	-	-	-

EFFECT OF STATISTICAL PARAMETERS ON WEAR LOSS

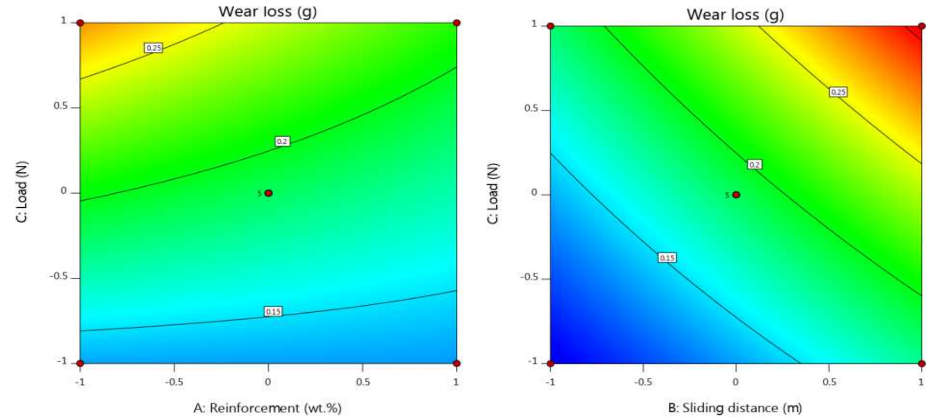
From the consequences of the ANOVA Table 5, a model acceptabilityinspection was executed with a specific end goal to confirm that the quadratic model for WL of the regression study is not abused. The normal probability curve of the residual for WL is exposed in Figure 4a which demonstrates no signal of the destruction of the independence or constant hypothesis. Meanwhile,every point in the curve takes after a straight line sequence of action, including that the errors are scattered typically. The model accomplished could be utilized to predict the WL inside the points of confinement of the elements investigated. So as to look into the impacts of independent parameters on WL, the two-dimensional (2D) plot and showed in Figure 4 (b-d) independently. Figures 4b and 4c show the 2D plot for WL with the change of reinforcement × L × SD, entirely. Similarly, Figure 4d exhibits the 2D response surface plot for WL with the change of L × SD, entirely.



(a)



(b)



(c) **(d)**

Figure 4: (a) Shows the Normal Probability Plot on Wear Loss and (b, c, d) Shows the 3D Surface Plot for Wear Loss of Load, Reinforcement and Sliding Distance

The results from Figures 4b and 4c show that the WL reduces with a rise in the L, SD against reinforcement. This occasion might be begun owing to the head way of a skinny carbon film at the sliding direction in view of the reaction between the steel and Al-12Si-xB_4C composites in the incorporating air and moreover, the thin oxide layer can similarly go about as solid oil in this way reducing the wear misfortune. In like manner the outcomes from Figure 4d display that the WL rises with a development in the L and SD [14]. This could be a result of the reason that with an extension in the SD the temperature augmentations to a fundamental motivating force at which the Al-12Si-xB_4C case surface advances toward getting to be chipped since of its small thermal conductivity. This rusty surface of Al-12Si-xB_4C whichever becomes partitioned or winds up detectable steady to certain degree [9]. The molded separated oxide film or an element occasionally goes about as lubing and thusly this oxide film diminishes the WL. The wear resistance of the composites is impressively upgraded because of the consideration of the B_4C nanoparticles and ascends with expanding B_4C weight portion up to 8 wt. %. For the most part, the improved wear resistance of all composites is the presence of B_4C nanoparticles whose hardness is greatly improved than the matrix alloy [15]. It is notable that hard B_4C nanoparticles in the matrix alloy arrangement fortifying to the softer matrix amid sliding and strengthening the Al-12Si matrix. This fortifying will confine the deformation, and furthermore, opposes the penetration and harming of the asperities of the sliding plate into the surface of the composites. The B_4C nanoparticles additionally enhance stack bearing limit and warm dependability of the composites. Additionally, WL was diminished, because of the expansion in hardness of the Al-12Si-xB_4C composites. This is because of the incorporation of secondary B_4C nanoparticle fortified on the delicate Al-12Si matrix.

CONCLUSIONS

In the current examination, the Al-Si-xB_4C composites were tried against steel counter body for various loads and sliding distances. The consequent conclusions can be drawn in view of the experimental work:

- The hardness of the Al-Si-xB_4C composites was expanded with expanding B_4C content support into the Al-Si matrix.
- In view of the consequences of ANOVA, the polynomial models of the WL are all around fitted to the trialreadings. The effect of the wear factors on the WL was considered by the mathematical model.

- The results are influenced that all factors have the significant effect on the wear loss at 95 % confidence level. Aggressive and synergistic interfaces between the variables have been shown statistically through RSM design and by application of the normal probability plot investigation.
- The WL of the composites diminishes with the increase of B_4C particlessupports and furthermore, in the meantime, it increments with increment in L and SD individually.
- SEM examination of the worn surface investigation shows that the upgrade in hardness and a change in the wear conduct of the composite materials were contemplated.

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